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COST-EFFECTIVENESS ANALYSES

by

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William Sacco
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March 1966

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U. S. ARMY MATERIEL COMMAND
BALLISTIC RESEARCH LABORATORIES
ABERDEEN PROVING GROUND, MARYLAND

B A L L I S T I C   R E S E A R C H   L A B O R A T O R I E S

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MARCH 1966

COST-EFFECTIVENESS ANALYSES

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RDT&E Project No. 1P523801A098

A B E R D E E N   P R O V I N G   G R O U N D ,   M A R Y L A N D

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DDO'Neill/WSacco/DPWesterman/nlb
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COST-EFFECTIVENESS ANALYSES

ABSTRACT

Methods for the conduct of cost-effectiveness studies and formats for the presentation of results are presented.

TABLE OF CONTENTS

I. INTRODUCTION

The need for a cost-effectiveness analysis occurs when there are alternative means of obtaining a desired objective. In evaluating weapon systems, this analysis usually contains certain basic ingredients*: the desired effectiveness against a potential threat (objective); well defined weapon families and weapon systems (alternative means); measures of worth (cost and effectiveness); and a method of integrating these basic elements (methodology). Furthermore, the results must be reported in an objective fashion.

The purpose of this paper is to present the general procedures for the conduct of a cost-effectiveness analysis and to indicate the format for presentation of the results. Although the discussion is oriented toward the evaluation of surface-to-surface artillery and tactical aircraft, the basic concepts are applicable to analyses of other weapon types.

II. DISCUSSION

A. General

The methodology employed in conducting most analyses is predicated on the premise that the worth of a new weapon system is based on the total expenditures required to develop, build, field, and maintain an organization of weapons in peacetime and the potential wartime effectiveness procured with these resources.

Furthermore, its capability should be measured, not by its performance as an individual weapon, but as a member of a family of weapons. Accordingly, a cost-effectiveness analysis is aimed at an

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*The Appendix to this paper presents the basic elements of a cost-effectiveness analysis as well as a detailed break-out of their composition.

evaluation of the relative worth of alternative weapon mixes in attacking a series of typical enemy threats. Figure 1 presents schematically the methodology for this type of cost-effectiveness study. The following discussion gives a brief description or mathematical statement of each of the major areas shown in Figure 1.

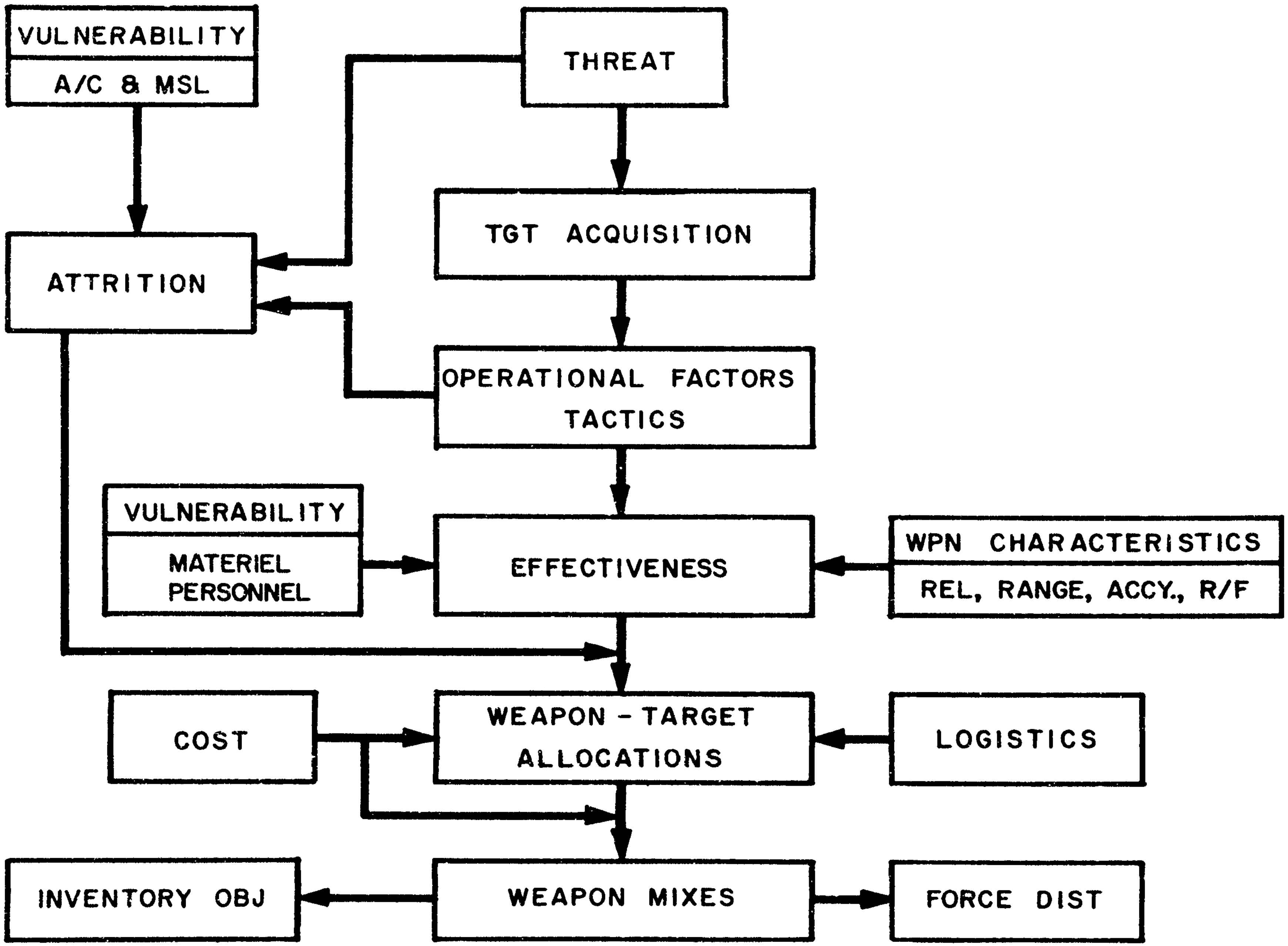
B. Threat

The threat utilized in a cost-effectiveness study may be static or dynamic. The static threat, representing a point in time in an assumed conflict, obviously does not express the time-movement factors of battle. At the present state-of-the-art, war gaming is a laborious time consuming task that must be repeated many times in order that a sufficiently large sample may be obtained. The solution to this dilemma, then, lies somewhere betwixt the two. Therefore, in order that the dynamics of a war may better be approximated, the threat employed may be based on a progressive series of time-dependent, static target arrays that describe typical enemy tactical situations. Thus, some of the major objections to both the static and dynamic representations are eliminated.

C. Target Acquisition

A sophistication of the target acquisition analysis is obviously partially dependent upon the type of threat analysis that precedes it. In its more sophisticated form, target acquisition is simulated by a time-dependent analysis of a progressive series of static target arrays. The type of input information and its flow closely parallels that which would occur in a combat environment. This analysis results in a set of targets that represent acquisitions during, at a minimum, the time period of the overlays. Each acquired target in the threat is described in terms of an estimated target type (i.e. personnel, materiel, etc.), desired attack criterion, estimated size, location

FIGURE 1 - METHODOLOGY



error, target duration, and, if a personnel target, the time-posture sequence of troops in the target area.

D. Effectiveness

For each weapon considered in the analysis, the number of rounds or aircraft sorties required to achieve the desired attack criterion against each acquired target is determined on the basis of target vulnerability and weapon characteristics such as range, accuracy, reliability, rate-of-fire, payload and munitions lethality. Also certain constraints and operational factors regarding weapon employment and fire mode are employed.

E. Attrition

The effectiveness computations are modified by an attrition analysis which determines the additional rounds or aircraft sorties required to attack the acquired targets for those conditions in which the enemy air defense weapons are active. The inputs to the attrition analysis result from studies whose scope may range from a limited parameterization of attrition rates to a much broader parameterization of attrition environment in which the capability of enemy air defense weapons is analyzed against friendly weapons.

F. Weapon-Target Allocations

After the number of rounds required to attack each of the acquired targets is computed, weapons are allocated to all of these targets. Three allocation schemes which have been developed are based on: (1) minimizing the cost or weight of ammunition required; (2) maximizing the effectiveness of the weapon family; and (3) minimizing the total cost of the artillery family. These three weapon-target allocation models are presented in following sections as well as the associated cost models, logistical constraints and examples of results.

1. Maximizing Effectiveness[(1)*].

a. Statement of the Problem. -- The problem is one of a class of weapon-target allocation problems of current interest to the Weapon Systems Laboratory of the Ballistic Research Laboratories. We shall use the following notations and definitions in the description of the problem:

T_j - denotes the j^{th} target class[**]; $j = 1,2,\ldots s$

f_j - number of targets in the j^{th} target class; $j = 1,2,\ldots s$

W_i - weapon type i; $i = 1,2,\ldots m$

r_{ij} - the number of rounds (sorties) of ammunition required to defeat target T_j with the i^{th} weapon

n_i - number of rounds (sorties) available for weapon W_i ("Combat day's expenditure")

X_{ij} - the number of targets of the j^{th} class of a single threat assigned to the i^{th} weapon.

The threat then is represented by the set of couples:

$$T = \{(T_j\ f_j)\};\ j = 1,2,\ldots s. \tag{1}$$

The problem is to determine the largest number of times, K, that the threat can be defeated using the available supply of ammunition. Specifically the problem can be stated as:

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*Superscripts refer to entries in the list of references.

**Targets of a given type, size and location.

Determine the X_{ij} which maximize K, subject to:

$$K[r_{11} X_{11} + r_{12} X_{12} + \dots + r_{1s} X_{1s}] \leq n_1$$

$$K[r_{21} X_{21} + r_{22} X_{22} + \dots + r_{2s} X_{2s}] \leq n_2$$

$$\dots\dots\dots\dots\dots\dots\dots\dots\dots$$

$$K[r_{m1} X_{m1} + r_{m2} X_{m2} + \dots + r_{ms} X_{ms}] \leq n_m$$

$$(2)$$

$$X_{11} + X_{21} + \dots + X_{m1} = f_1$$

$$X_{12} + X_{22} + \dots + X_{m2} = f_2$$

$$\dots\dots\dots\dots\dots$$

$$X_{1s} + X_{2s} + \dots + X_{ms} = f_s$$

$$X_{ij} \geq 0$$

where r_{ij}, n_i and f_j are given.

The values of K and X_{ij} are not to be restricted to integers. By introducing the "slack" variables, L_i, i = 1,2,...m, we obtain the following linear equations:

$$K[r_{11} X_{11} + r_{12} X_{12} + \dots + r_{1s} X_{1s} + L_1] = n_1$$

$$K[r_{21} X_{21} + r_{22} X_{22} + \dots + r_{2s} X_{2s} + L_2] = n_2$$

$$\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \qquad (3)$$

$$K[r_{m1} X_{m1} + r_{m2} X_{m2} + \dots + r_{ms} X_{ms} + L_m] = n_m$$

$$X_{11} + X_{21} + \dots X_{m1} = f_1$$

$$X_{12} + X_{22} + \dots X_{m2} = f_2 \qquad (3)$$

$$\dots\dots\dots\dots\dots$$

$$X_{1s} + X_{2s} + \dots + X_{ms} = f_s$$

$$L_i \geq 0.$$

b. Computer Application. -- The problem can then be converted into the form of classical linear programming by letting:

$$K = \frac{n_1}{[r_{11} X_{11} + r_{12} X_{12} + \dots r_{1s} X_{1s} + L_1]} ; \qquad (4)$$

then we have the problem

$$\min \frac{1}{n_1} [r_{11} X_{11} + r_{12} X_{12} + \dots + r_{1s} X_{1s} + L_1] \qquad (5)$$

subject to:

$$n_1 [r_{21} X_{21} + r_{22} X_{22} + \dots + r_{2s} X_{2s} + L_2] =$$
$$n_2 [r_{11} X_{11} + r_{12} X_{12} + \dots + r_{1s} X_{1s} + L_1]$$
$$n_1 [r_{31} X_{31} + r_{32} X_{32} + \dots + r_{3s} X_{3s} + L_3] =$$
$$n_3 [r_{11} X_{11} + r_{12} X_{12} + \dots + r_{1s} X_{1s} + L_1]$$

$$\dots\dots\dots\dots\dots\dots\dots\dots$$

$$\dots\dots\dots\dots\dots\dots\dots\dots \qquad (6)$$

$$n_1 [r_{m1} X_{m1} + r_{m2} X_{m2} + \dots + r_{ms} X_{ms} + L_m] =$$
$$n_m [r_{11} X_{11} + r_{12} X_{12} + \dots + r_{1s} X_{1s} + L_1]$$

$$
\begin{aligned}
X_{11} + X_{21} + \dots + X_{m1} &= f_1 \\
X_{12} + X_{22} + \dots + X_{m2} &= f_2 \\
\dots\dots\dots\dots\dots & \qquad (6) \\
X_{1s} + X_{2s} + \dots + X_{ms} &= f_s
\end{aligned}
$$

or equivalently $$\frac{1}{n_1} \min \lfloor r_{11} X_{11} + r_{12} X_{12} + \dots r_{1s} X_{1s} + L_1], \qquad (7)$$

subject to $$\begin{aligned} AX &= b \\ X_{ij} &\geq 0 \end{aligned} \qquad (8)$$

where

$$X = \begin{pmatrix} X_{11} \\ X_{12} \\ X_{13} \\ \vdots \\ X_{1s} \\ L_1 \\ X_{21} \\ X_{22} \\ \vdots \\ X_{2s} \\ L_2 \\ \vdots \\ X_{m1} \\ X_{m2} \\ \vdots \\ X_{ms} \\ L_m \end{pmatrix} \qquad b = \begin{pmatrix} \left.\begin{matrix} 0 \\ 0 \\ \vdots \\ 0 \end{matrix}\right\} \text{first } (m - 1) \text{ terms} \\ f_1 \\ f_2 \\ \vdots \\ f_s \end{pmatrix} \qquad (9)$$

and $A = (a_{ij})$ is the coefficient matrix.

Any standard linear programming algorithm can be applied to the problem.

c. Logistic Constraint. -- The logistic constraint, n_i, utilized in this type of allocation is shown in the following equation:

$$n_i = B_i + R_{ci} - R_{oi} \tag{10}$$

where n_i is the number of rounds of ammunition of weapon W_i available in a day of "intense combat"

B_i is the basic load of ammunition carried with weapon W_i

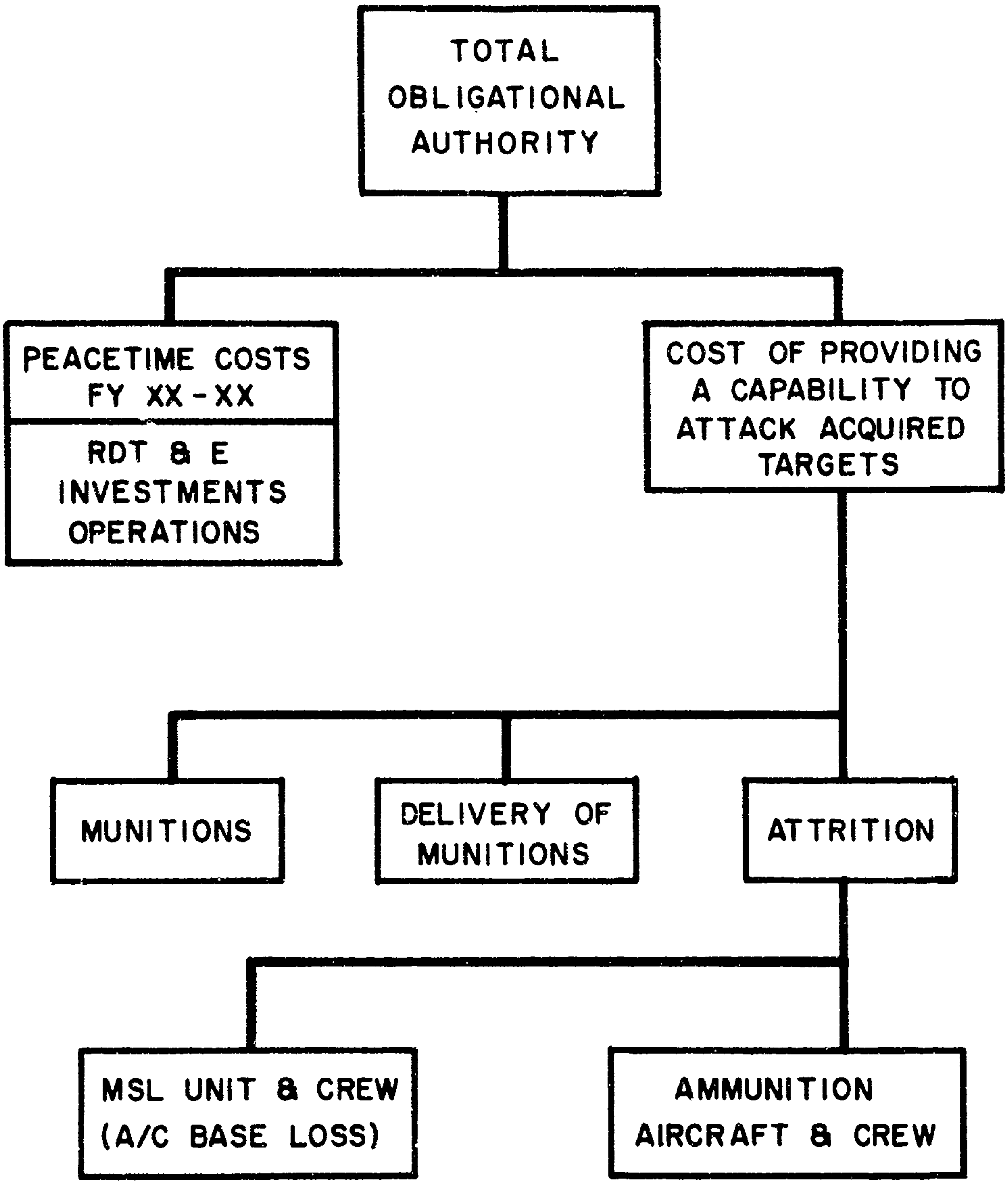
R_{ci} is weapon W_i's share of that quantity of ammunition which can be supplied in one day to the firing unit by those vehicles organic to the firing unit

R_{oi} represents those rounds required for registration, harassment and interdiction missions plus those "non-lethal" rounds in the basic load such as smoke, chemical and white phosphorus.

The term, n_i, then establishes a day of combat for each weapon.

d. Cost. -- The cost model associated with this allocation is shown in Figure 2. Costs are divided into two categories: research and development, investment and peacetime operating costs exclusive of "lethal" ammunition; and the cost of providing a capability to attack the threat, including aircraft and munitions attrition costs. A ten year period is considered for the period of peacetime operation. Any funds allocated prior to the initial fiscal year are considered "sunk" funds and are not included in the study. However, any assets procured with these funds are treated as available and free of cost. In addition, the cost of an interim capability is charged to a

FIGURE 2
COST ACCOUNTING



"phased-in" weapon system. Therefore, this cost accounting model describes the funding required in order that a capability can be attained by a point in time.

e. Results. -- The results of this allocation give the decision maker the capability to choose his limiting values of cost, threat level and rate of attack. This is accomplished through the use of the logistical constraint in describing the basic unit of effectiveness as shown in Figure 3. In this figure, the left hand box represents, for each alternative weapon mix, a division slice of weapons from the total force. One threat, then, may be defined as the acquired enemy targets opposing one friendly division. Within the logistical constraints – that is the number of rounds that could be fired by each weapon in one day of intense combat (n_i) – the weapons in the one division slice are allocated to the acquired targets so as to maximize the number of threats that can be attacked in one day of intense combat. By considering successive days of intense combat, curves are generated which relate level of effectiveness, in terms of the number of threats attacked, to total cost and rate of attack. The first curve, total cost, is shown in Figure 4 as a function of the number of threats attacked. The point on the ordinate of each curve represents the total ten year peacetime R&D, investment and operating costs, exclusive of lethal munitions, for the total artillery force. The functional relationship stems from the increase in funds required to provide the capability of attacking an increasing number of threats. The rate of attack presentation is shown in Figure 5. Additional figures may be generated that show munition requirements and force levels as a function of threat level.

2. Minimizing Cost and Weight of Ammunition.

a. Statement of the Problem. -- The basic question arises from the use of various types of weapons to attack (achieve a certain

FIGURE 3
BASIC UNIT OF EFFECTIVENESS

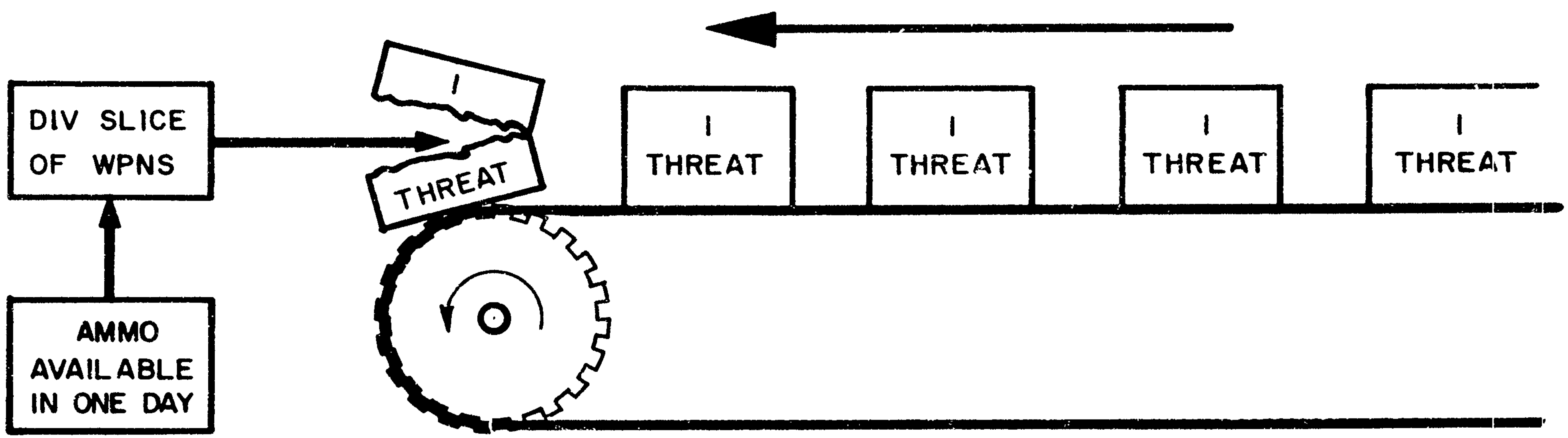


FIGURE 4
COST VS. EFFECTIVENESS

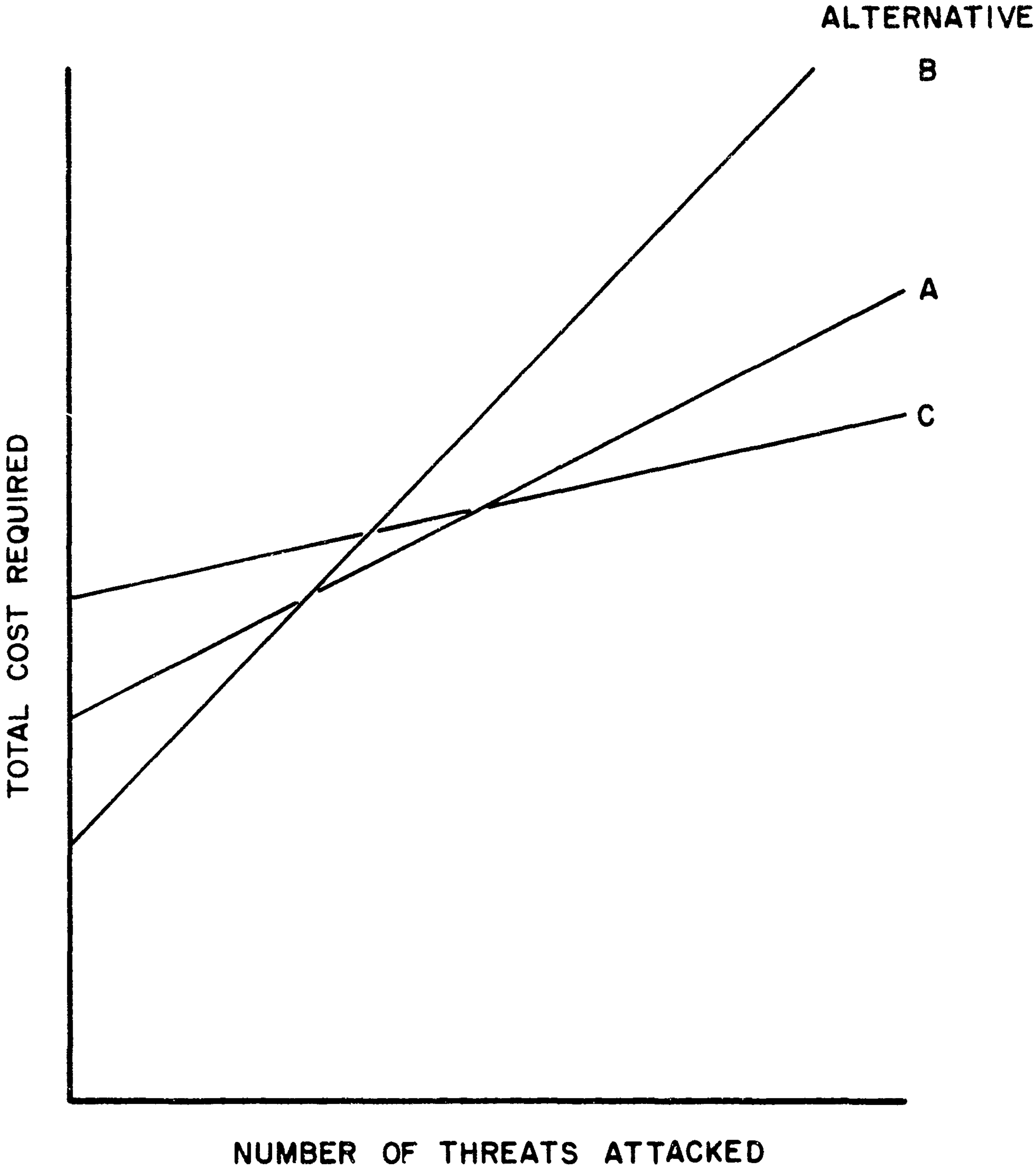
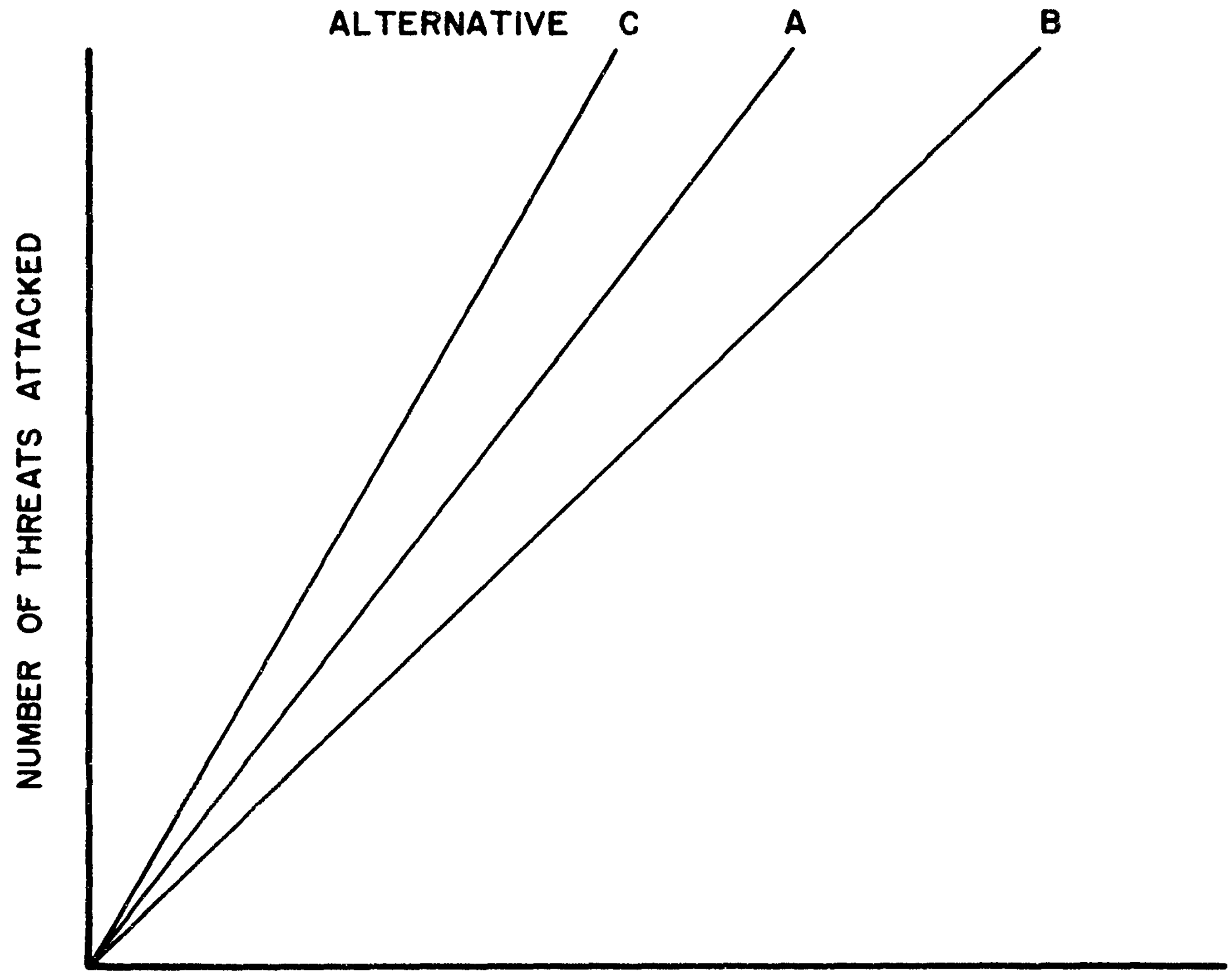


FIGURE 5
CAPABILITY



level of effectiveness) each target in a target complex (set of targets) in an efficient manner. Suppose that one has at his disposal a set of weapons which can be assigned to the various targets in a target complex. Each weapon-target combination is characterized by two numbers, the weight and cost of ammunition required to defeat the target. It is rarely possible to allocate weapons to targets such that both the total weight and the total cost of ammunition are minimized simultaneously. The problem, therefore, is formulated such that weapons are allocated to targets so as to minimize the total cost of ammunition required to defeat the target complex <u>subject</u> to the conditions that the total weight of ammunition used against the target complex does not exceed a given amount and that one and only one weapon is employed against each target in the target complex.

In outlining the problem we shall use the following notations and definitions:

W_{ij} - The weight of ammunition from weapon j that is required to attack target i

C_j - The cost of a unit weight of ammunition from weapon j

m - The number of weapons

n - The number of targets.

Since each target is to be attacked by one and only one weapon and the W_{ij}'s and C_j's given as inputs completely characterize the weapon-target relationships, one can determine (by inspection) the assignments of weapons to targets which yield the minimum total weight $W_o = \sum_{i=1}^{n} \underset{j}{\text{Min}} \; W_{ij}$, and the minimum total cost, C_o.

In general the assignment which gives the minimum total weight does not coincide with the assignment which provides the minimum

total cost. It is necessary, therefore, to determine a family of alternative solutions which represents trade-offs between cost and weight. If we denote an allocation vector (an assignment of weapons to targets) by the symbol $(\alpha_1,\alpha_2,\ldots,\alpha_n)$ where $\alpha_i \in \{1,2,\ldots,m\}$, then the cost function F is defined by the expression

$$F(\alpha_1,\alpha_2,\ldots,\alpha_n) = C_{\alpha_1} W_{1\alpha_1} + C_{\alpha_2} W_{2\alpha_2} + \ldots + C_{\alpha_n} W_{n\alpha_n}. \tag{11}$$

The problem then is to choose a set of α_i's that minimize $F(\alpha_1,\alpha_2,\ldots,\alpha_n)$ subject to the following constraint:

$$W_{1\alpha_1} + W_{2\alpha_2} + \ldots + W_{n\alpha_n} \leq r\, W_o, \tag{12}$$

where $r \geq 1$.

If the number of elements in S, the set of all admissible allocation vectors, is small then we can classify the problem as trivial. If, however, S possesses many elements, it is worthwhile to seek a more efficient technique than direct enumeration (element-by-element examination). As an example, we have been interested in problems with as many as 82 targets and 11 weapons. To resolve this problem for large values of r one may be required to consider as many as 11^{82} allocation vectors. The computing time involved in the enumeration of $F(\alpha_1,\alpha_2,\ldots,\alpha_n)$ would exceed the lifetime of any modern day computer. We will reformulate the problem as a multi-stage process and apply the functional equation techniques of dynamic programming[3] to obtain a feasible computational scheme. It is important to consider the advantage of using the functional equation technique. Our goal shall be the reduction of this n dimensional problem to a sequence of one-dimensional problems. The ith stage of the process will result in a determination of an α_i. To attain this simplification, we imbed this problem within a family of

similar problems. That is, instead of considering a particular weight of resources $r\ W_o$, and a fixed number of targets n, we consider an entire family of problems where the weight may assume any value less than $r\ W_o$ and the number of targets may be any natural number less than or equal to n. This approach has many computational advantages and enables one to obtain vital information about the change in optimal policies as the basic parameters r, W_o and n vary. Surprisingly it is easier (computationally) to treat the original problem by consideration of the family of problems.

b. Computer Application. -- In order to treat this minimization problem by means of functional equation techniques, we shall introduce the function $f_k(z)$, defined for $o \leq z \leq r\ W_o$, and $k = 1,2,\ldots n$ by the relation

$$f_k(z) = \min_{\{\alpha_1,\ldots,\alpha_k\}} F(\alpha_1,\alpha_2,\ldots,\alpha_k), \text{ where} \quad (13)$$

$$\alpha_i \epsilon \{1,2,\ldots,m\} \text{ and } W_{1\alpha_1} + W_{1\alpha_2} + \ldots + W_{k\alpha_k} \leq z.$$

Then $f_k(z)$ represents the minimum cost associated with a problem involving k targets and the weight resource $z(o \leq z \leq r\ W_o)$. The minimization involved in the above equation can be accomplished in k one-dimensional minimization processes by employing Bellman's <u>Principle of Optimality</u>. We have then

$$f_k(z) = \min_{\alpha_k} \left[C_{\alpha_k} W_{k\alpha_k} + f_{k-1}\ (z - W_{k\alpha_k}) \right] \ ; \ k = 2,3,\ldots,n. \quad (14)$$

When k = 1,

$$f_1(z) = \min_{\alpha_1} C_{\alpha_1} W_{1\alpha_1}, \text{ where } W_{1\alpha_1} \leq z. \quad (15)$$

The statement of this problem includes the requirement that each of the targets must be defeated. It follows for the evaluation of $f_k(z)$, that z is bounded below by the minimum weight $W_o^{(k)} = \sum_{i=1}^{k} \underset{j}{\text{Min}}\, W_{ij}$ which is required to defeat the first k targets. Furthermore, it is not necessary to compute $f_k(z)$ for z greater than

$$\text{Min} \left\{ \sum_{i=1}^{k} \underset{j}{\text{Max}}\, W_{ij},\ rW_o - W_o + W_o^{(k)} \right\}.$$

Indeed, when $z = \sum_{i=1}^{k} \underset{j}{\text{Max}}\, W_{ij}$, one has permitted consideration of all possible policies for the first k targets and any further increase in z could not produce a smaller cost. The second constraint in the brackets arises because we are required to conserve enough weight to defeat the remaining n - k targets. This remaining weight must not be less than $\sum_{i=k+1}^{n} \underset{j}{\text{Min}}\, \{W_{ij}\}$. Hence z should not exceed

$$\left(rW_o - \sum_{i=k+1}^{n} \underset{j}{\text{Min}}\, \{W_{ij}\} \right) = rW_o - W_o + W_o^{(k)}.$$

c Cost - Results. -- The cost model is simply a summation of the ammunition costs and weights* required by alternatives to attack a threat. See Figures 6 and 7.

d. Logistic Constraint - Results. -- The logistic constraint is as stated in equation (12),

$$W_{1d_1} + W_{2d_2} + \ldots W_{nd_n} \leq rW_o, \text{ where } r \geq 1.$$

*In this allocation, weight is assumed to be an indicator of logistic burden or cost.

FIGURE 6
TOTAL COST OF AMMUNITION
REQUIRED TO ATTACK A THREAT

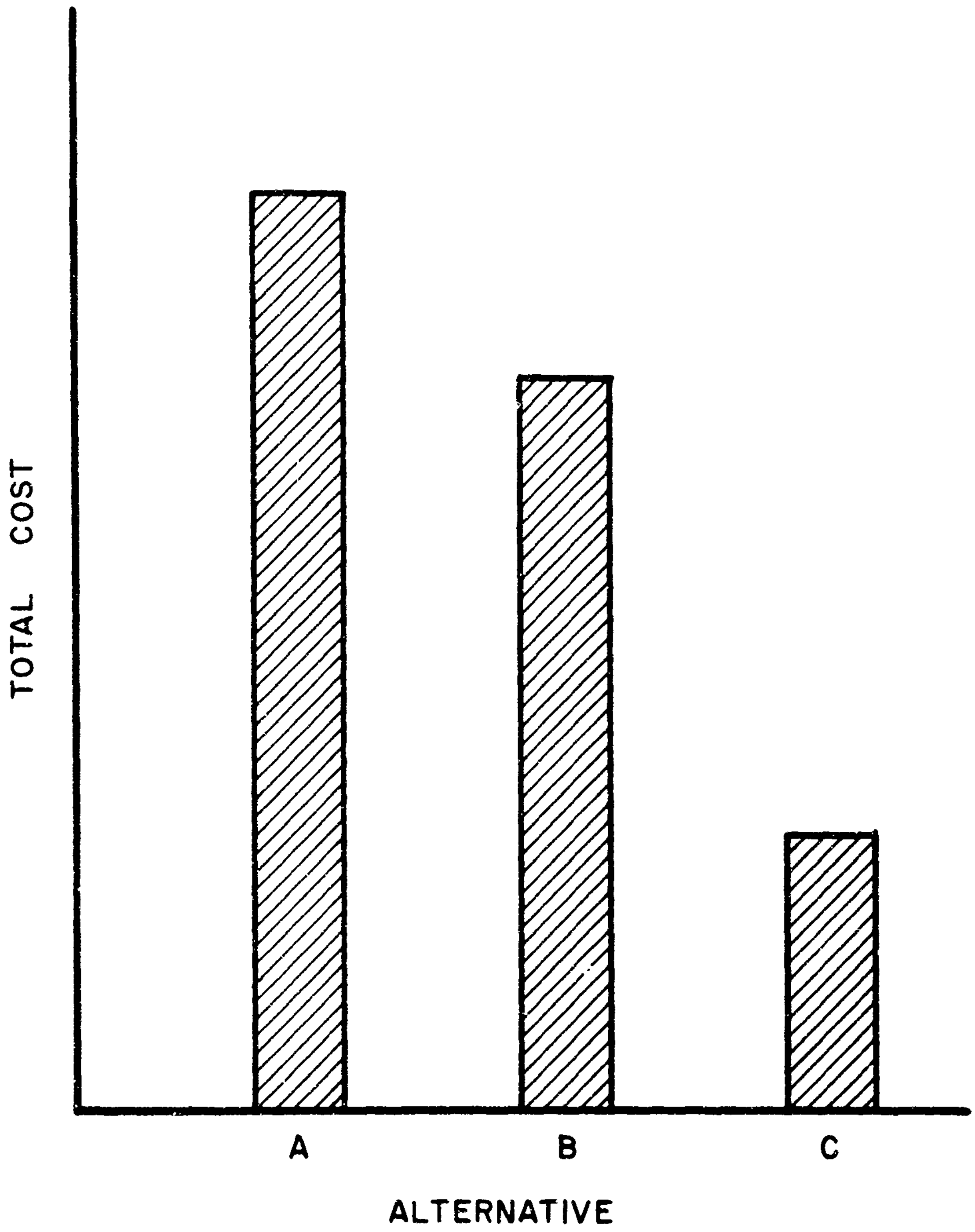
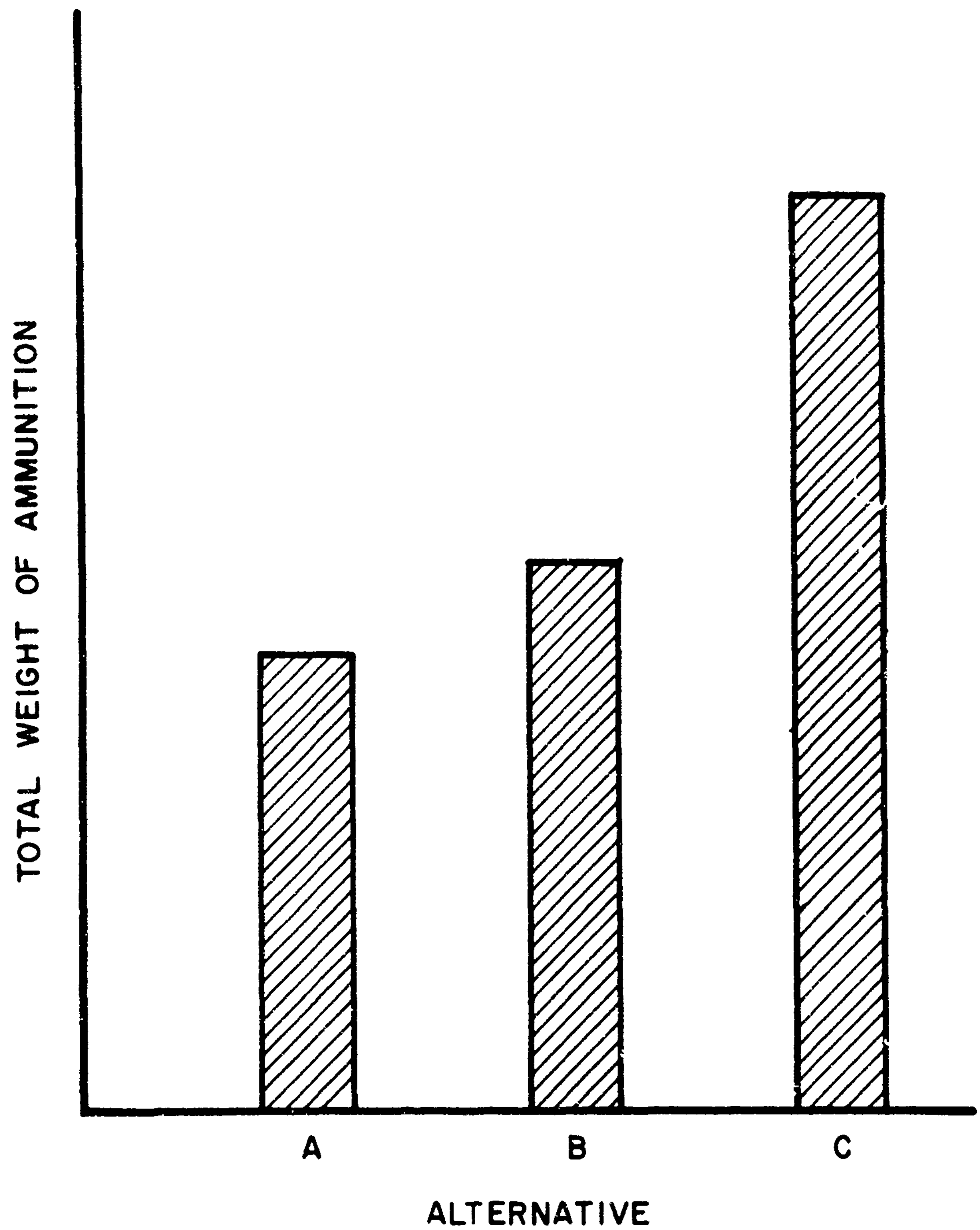


FIGURE 7
TOTAL WEIGHT OF AMMUNITION
REQUIRED TO ATTACK A THREAT



Relaxation of the minimum weight constraint, W_o, by considering increasing incremental values of r, will yield a curve such as Figure 8.

3. Minimizing Total Cost.

a. Statement of the Problem. -- We are given that a set of weapons $W = \{W_1, \ldots, W_m\}$ is available against a set of targets $\{T_1, \ldots, T_\ell\}$. Associated with each weapon W_i is a cost function $g_i(n_i)$ which gives the cost of n_i rounds of the type of ammunition used by weapon W_i. The weapons in the set W represent several weapon families, F_i. The set W is ordered so that $F_1 = \{W_1, W_2, \ldots, W_{\lambda_1}\}$. $F_2 = \{W_{\lambda_1+1}, \ldots, W_{\lambda_2}\}, \ldots, F_k = \{W_{\lambda_{k-1}+1}, \ldots, W_m\}$. Associated with each weapon family is an additional organizational cost $g_{F_i}(N_i)$ where N_i represents the sum of the rounds of ammunition used by weapons belonging to the family F_i. A weapon-target relationship is characterized by the number, r_{ij}, of rounds of ammunition of W_i required to defeat the target T_j.

The problem is to assign one and only one type of weapon to each target in such a way that the total cost of defeating the entire set of targets is a minimum.

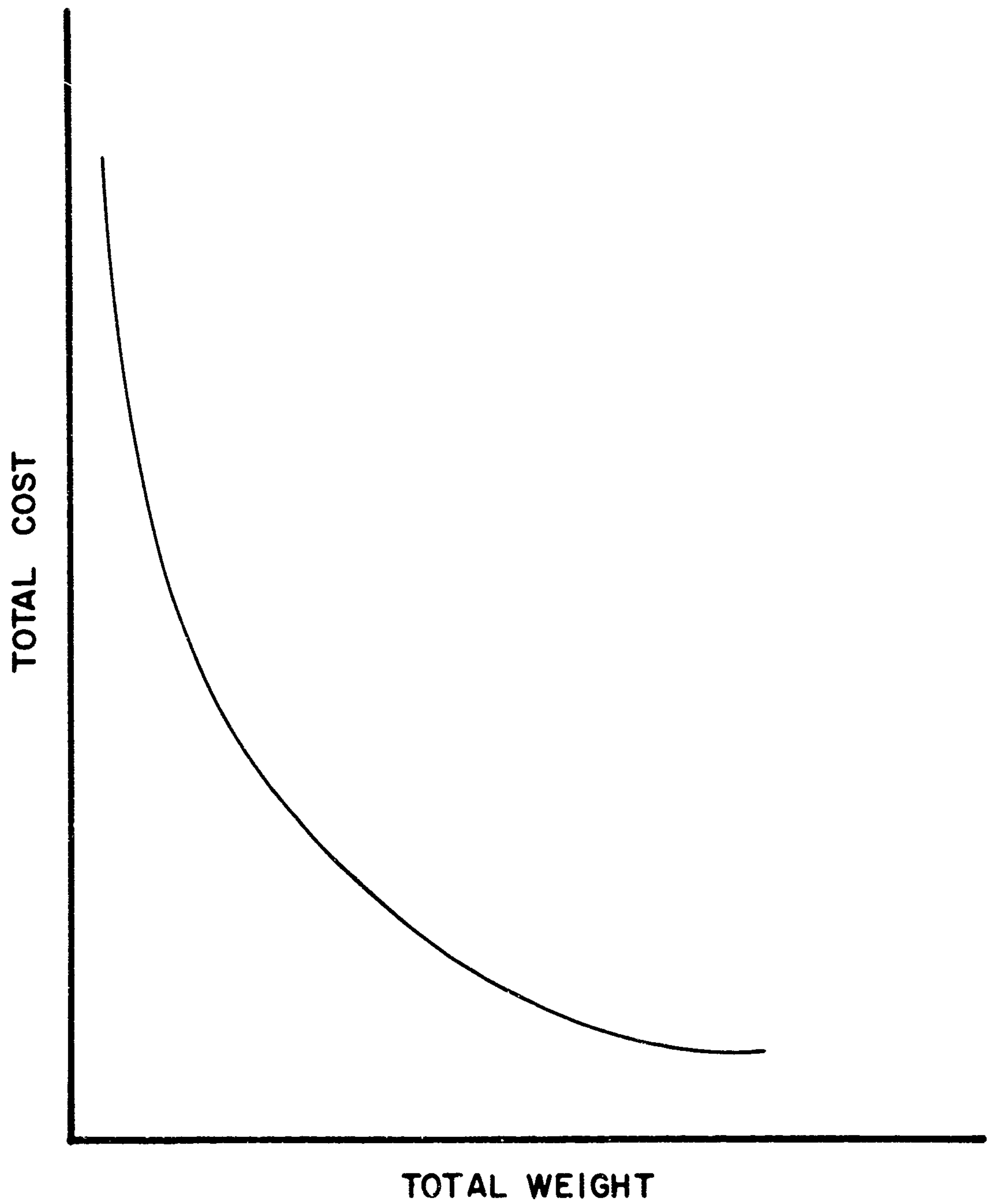
Specifically, the problem is to find a set of δ_{ij} which will minimize $h(\delta)$ =

$$g_1(n_1) + g_2(n_2) + \ldots + g_m(n_m) + g_{F_1}(N_1) + g_{F_2}(N_2) + \ldots + g_{F_k}(N_k) \qquad (16)$$

subject to the constraints:

$$\begin{aligned}
\delta_{11} + \delta_{21} + \ldots + \delta_{m1} &= 1 \\
\delta_{12} + \delta_{22} + \ldots + \delta_{m2} &= 1 \\
\ldots\ldots\ldots\ldots & \\
\delta_{1\ell} + \delta_{2\ell} + \ldots + \delta_{m\ell} &= 1 \\
\delta_{ij} &= 0 \text{ or } 1,
\end{aligned} \qquad (17)$$

FIGURE 8
TOTAL COST AND WEIGHT OF AMMUNITION REQUIRED TO ATTACK A THREAT



where

$$n_i = \sum_{j=1}^{\ell} \delta_{ij}\, r_{ij} \qquad (i = 1,2,\ldots,m),$$

$$N_1 = n_1 + n_2 + \ldots + n_{\lambda_1},$$

$$N_2 = n_{\lambda_1+1} + \ldots + n_{\lambda_2}, \tag{18}$$

$$\cdots\cdots\cdots$$

$$N_k = n_{\lambda_{k-1}+1} + \ldots + n_m,$$

$$\delta_{ij} = \begin{cases} 1 \text{ if } W_i \text{ is assigned to } T_j \\ 0 \text{ otherwise} \end{cases},$$

and

$$\delta = (\delta_{11}, \delta_{21}, \ldots, \delta_{m1}; \delta_{12}, \delta_{22}, \ldots, \delta_{m2}; \ldots; \delta_{1\ell}, \delta_{2\ell}, \ldots, \delta_{m\ell}).$$

b. Computer Application. -- As the functions, g_i, are non-linear, this problem is a non-linear, integer programming problem by virtue of the form of both the objective function (16) and the constraining equations (17).

The following procedure is used to search for a solution: Starting with any arbitrary point, δ, a local search technique is used to move to better points until no further improvement is possible. It is then at a locally optimal point with respect to the search method. The procedure is then repeated for another starting point. The starting points are chosen according to a probability scheme. The minimum of all the local minima is chosen as the best solution to the problem. This approach is considered to provide a reasonably intelligent search procedure, but one for which no assurance can be given about the results obtained. The procedure

has been carried out for several actual problems of modest size ($m = 5$, $\ell = 28$) with what appears to be good success.

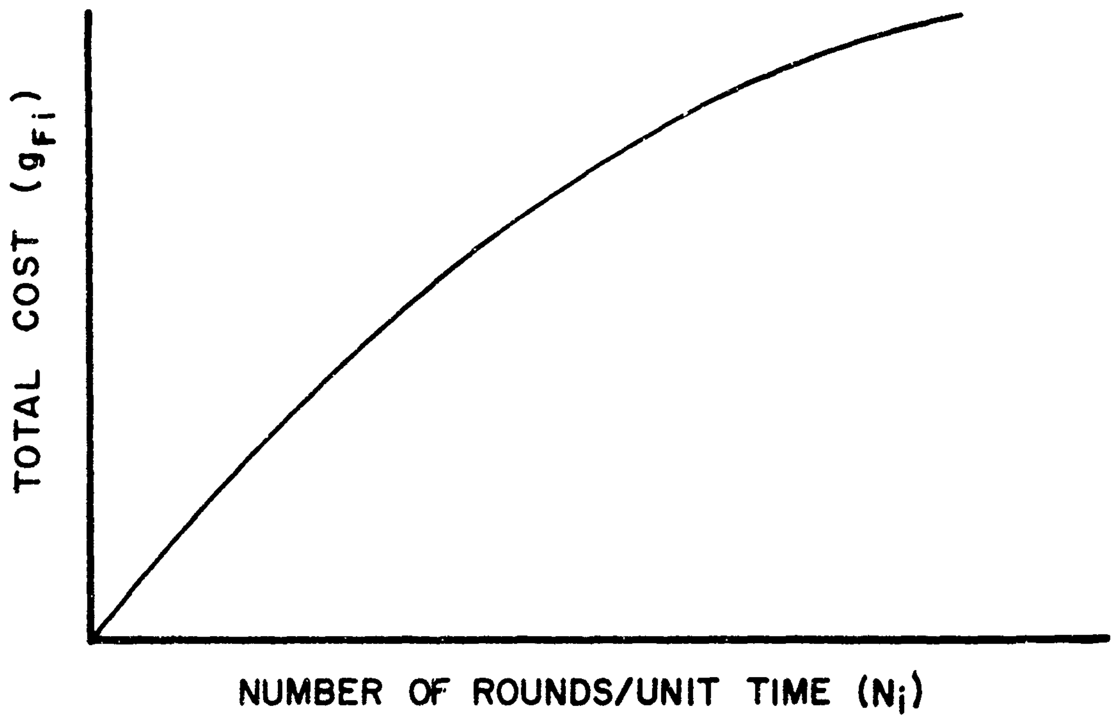
c. Cost - Logistic Constraint. -- The cost model for this allocation includes essentially the same elements as shown in Figure 2. In this case, however, all costs are inputs to the allocation. The form of the input is shown in Figure 9. Figure 9(A) shows the organizational cost as a function of the number of rounds fired per unit time. The parameter of rounds-per-unit-time can be either a resupply capability limitation similar to that in equation (9) or, in the event that logistical support is not fixed, it can be a limitation imposed by the physical capability of the tube-crew combination to fire rounds*. In either event, as the requirement for rounds increases more organizations must be fielded to meet the demand – thus the increase in organizational cost.

Figure 9(B) shows the function $g_i(n_i)$.

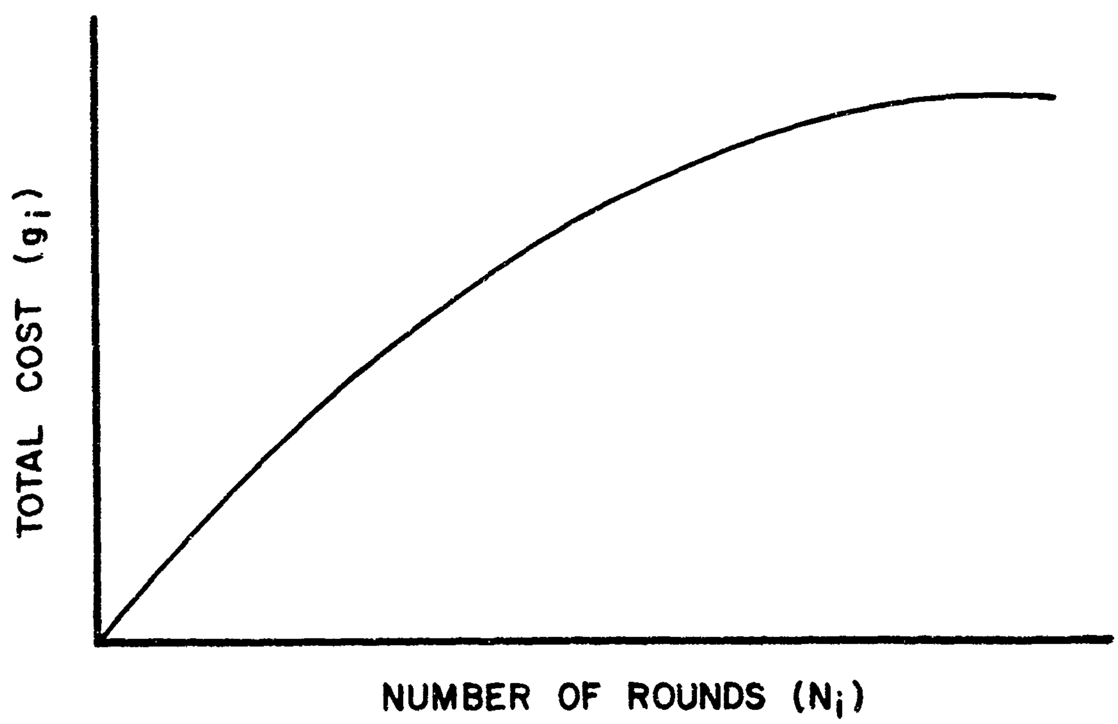
d. Results. -- Insufficient experience has been gained in the use of this allocation scheme to show a format for the presentation of results. However, the form of presentation would be quite similar to that shown in the other allocations.

*When the logistical "tail" is to remain fixed and, because of other considerations, an upper limit to the number of weapons is desired, it may be realized by assigning an infinite cost beyond the proper point on the abscissa of Figure 9(A). If, however, the logistic "tail" is flexible, then a third curve, "Total Logistical Cost", may be introduced which will also be a function of a number of rounds per unit time. This input may also be constrained by an infinite cost.

FIGURE 9
(A) ORGANIZATION COST



(B) AMMUNITION COST



III. SUMMARY

This report has attempted to introduce three general techniques for conducting cost-effectiveness analyses. The selection of the proper technique for a study is dependent upon the question to be answered and the time available for resolution.

DANIEL D. O'NEILL WILLIAM SACCO DEAN P. WESTERMAN

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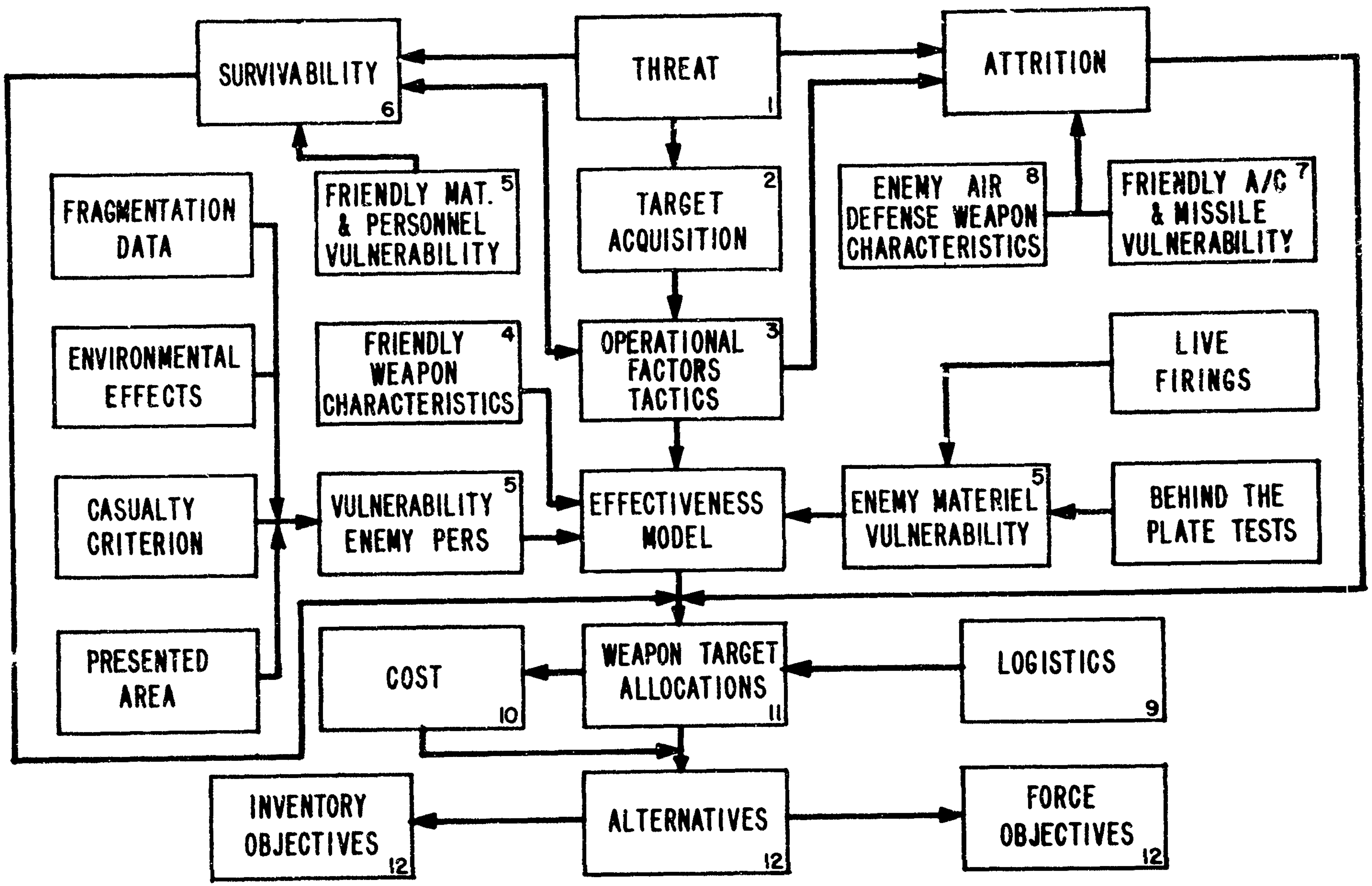
APPENDIX

COST-EFFECTIVENESS ANALYSIS

<u>Objectives</u>

1. Optimum System
2. Optimum Munition
3. Alternatives
4. Weapon Mixes
5. Inventory Objectives
6. Force Objectives
7. Optimum Allocation of Resources

METHODOLOGY



1. Threat

   1. Scale of Conflict (General - Guerrilla War)
   2. Degree of Sophistication
   3. Geographic Area
   4. Time Frame
   5. Climatic Conditions
   6. Force Level - Time Phased
      a. Initial
      b. Reserve
   7. Type Engagement (Offense - Defense)
   8. Time of Battle (H-1, H+3, etc.)
   9. Target Description
      a. Terrain (Including Degree of Cover)
      b. Size - Circular and Rectangular Measure
      c. Priority - Military Value
      d. Type - Unit Designation
      e. Number of Personnel
      f. Number and Types of Vehicles
      g. Number and Types of Weapons
      h. Distance from Reference Line
      i. Electromagnetic Profile
      j. Hardness by Element Category
      k. Target Element Description
      l. Defeat Criterion
         (1) Percent Casualties
         (2) Percent Damage
         (3) Time Limit
      m. Posture Sequence
      n. Permanence
      o. Rate of Movement
   10. Deployment (Nuclear - Non-Nuclear)

2. <u>Target Acquisition</u>

1. Sensor Characteristics
2. Employment Doctrine
3. Methodology of Analysis
    a. Target Location Error
    b. Processing Times
    c. Target Duration
    d. Target Identification Error
    e. Rate of Acquisition
    f. Acquisition Analyst Bias
    g. Time of Identification
    h. Acquisition Sensor
    i. Terrain Effects
    j. Weather Limitations
    k. Reliability
4. Susceptibility to Jamming
5. Sensor Vulnerability

3. Operational Factors

1. Firing Tactics
2. Deployment Depth
3. Unit Size
4. Unit Employment
5. Time of Emplacement
6. Time to Disassemble
7. Number of Missions
8. Number of Volleys
9. Resupply Rates
10. Troop Strength
11. Number of Sorties
12. Number of Passes
13. Attack Profile
14. Number of Planes
15. Availability
16. Force Size
17. Time-phased Force Deployment
18. Constraints
19. Mobility
20. Concealment
21. Cover
22. Command & Control

4. <u>Friendly Weapon Characteristics</u>

1. Accuracy
2. Range
3. System Reliability
4. Rate of Fire
5. Mission Profile
6. Response Time
7. Transportability
    a. Air Force Air
    b. Surface
8. Mobility
    a. Ground
    b. Army Air
9. Useful Service Life
10. Inventory Objective
11. Munitions (By Type)
    a. Nuclear or Non-Nuclear
    b. Storage Life
    c. Reliability
    d. Time Frame (Availability)
    e. Lethality
    f. Warning
12. Fuzing Characteristics
    a. Accuracy
    b. Reliability
    c. Susceptibility to Jamming
    d. Type of Fuze
13. Guidance System Characteristics and Vulnerability
14. Gross Weight
15. Crated Weight
16. Crated Volume
17. Counter - Fire Capability

5. Vulnerability, Friendly and Enemy Materiel/Personnel

1. Materiel
    a. Behind-the-plate Tests
    b. Live Firings Against Vehicles and Components
    c. Studies
2. Personnel
    a. Fragmentation Test
        Fragmentation Data
            (a) Mass, Velocity and Spatial Distribution of Fragments
            (b) Degradation
                1 Vegetation
                2 Foliage
    b. Wound Ballistics
        Casualty Criteria
    c. Terrain Surveys
        Presented Area Functions
    d. Personnel Training
    e. Personnel Equipment (Body Armor)
    f. Effects of Blast
3. Effect of Movement and Speed

6. Survivability

1. Launcher
2. Air Base
3. Command and Control Functions
4. Resupply Vehicles
5. Aircraft
6. Class III and V Storage
7. Personnel

7. Aircraft and Missile Vulnerability

1. Aircraft and Missile Materiel and Components
   - a. Plate Tests
   - b. Firings Against Aircraft and Missile Components
     - (1) Engines, Wing Sections, Fuselage Sections, Fuel Tanks and Lines, and Simulated Pilots for Aircraft
     - (2) Adaption Kits, Warheads, Guidance Packages, and Propulsion Systems for Missile
2. SAM and AA Projectiles vs Aircraft and Missile Materiel
   - a. Fragmentation Data
     - (1) Size, Velocity, Materiel
     - (2) Spatial Distribution
   - b. Penetration Data
     - (1) Initial and Residual Velocities
     - (2) Initial and Residual Mass
     - (3) Depth of Penetration
     - (4) Crater Size
3. Blast Data
   - a. Blast and g'Loading
   - b. Radiation and Heat Effects
4. Vulnerable Area Computations

8. <u>Enemy Air Defense Weapons Characteristics</u>

1. Accuracy
2. Range
3. Reliability
4. Lethality
5. Rate of Fire
6. Acquisition Capability
7. Response Time
8. Speed
9. Tracking Capabilities
10. Deployment
11. Employment
12. Terrain Limitations

9. Logistics

1. Type of War
2. Weapons Considered
3. Weight & Cubage Information
4. Maintenance Support Requirements
5. Basic Study Assumptions
6. Resupply Rate
7. Resupply Vehicle Description
8. Manpower Requirements
9. Ammo Handling Requirements
    a. Safety Requirements
    b. Ruggedness
    c. Security Requirements
10. Environmental Conditions
    a. Type of Road
    b. Availability of Roads
    c. Type of Airfield
    d. Availability of Airfield

10. Cost

1. RDTE
2. Investment
   a. System Peculiar Equipment -- PEMA
   b. Common Equipment -- PEMA
   c. Selected High Unit Cost Repair Parts -- PEMA
   d. Transitional Training -- OMA
   e. Initial Issue of Supplies
3. Operations
   a. Military Personnel, Army MPA
   b. OMA
   c. Recurring PEMA
4. Transportation
5. Phase-in
6. Phase-out
7. Life of System
8. Scrap (Salvage Value)
9. Available Resources
10. Geographic Deployment
11. Force Levels, Units
12. Force Levels, Equipment
13. Force Levels, Personnel
14. Mission Spectrum
15. Weight of Ammunition
16. Time Required to Defeat
17. Plutonium Equivalent Costs
18. Oralloy Equivalent Costs
19. Shadow Prices
20. Facilities

NOTE:

PEMA - Procurement of Equipment and Missiles, Army
OMA - Operations and Maintenance, Army
MPA - Military Personnel, Army

11. Weapon-Target Allocation

1. Type of War
2. Basic Study Assumptions
3. Weapons Considered
4. Lower Funding Limit (Fiscal Year)
5. Upper Funding Limit (Fiscal Year)
6. National Economic Philosophy
7. Basis of Allocation
    a. Value
    b. Dollar Cost
    c. Time
    d. Critical Material Cost
    e. Effectiveness
    f. Secondary Damage Area
    g. Available Resources
    h. Weight of Ammunition

12. Results

1. Alternatives
    a. Constant Effectiveness Basis
    b. Constant Cost Basis
2. Weapon Mixes
3. Inventory Objectives
4. Force Objectives
5. Optimum System
6. Optimum Munition

Unclassified
Security Classification

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13. ABSTRACT

Methods for the conduct of cost-effectiveness studies and formats for the presentation of results are presented.

Unclassified
Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Cost-Effectiveness Analysis						
Systems Analysis						
Economic Analysis						
Methodology						
Cost						
Resource Allocation						
Weapon-Target Allocations						

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